Development and formation process of sand dunes in Finland

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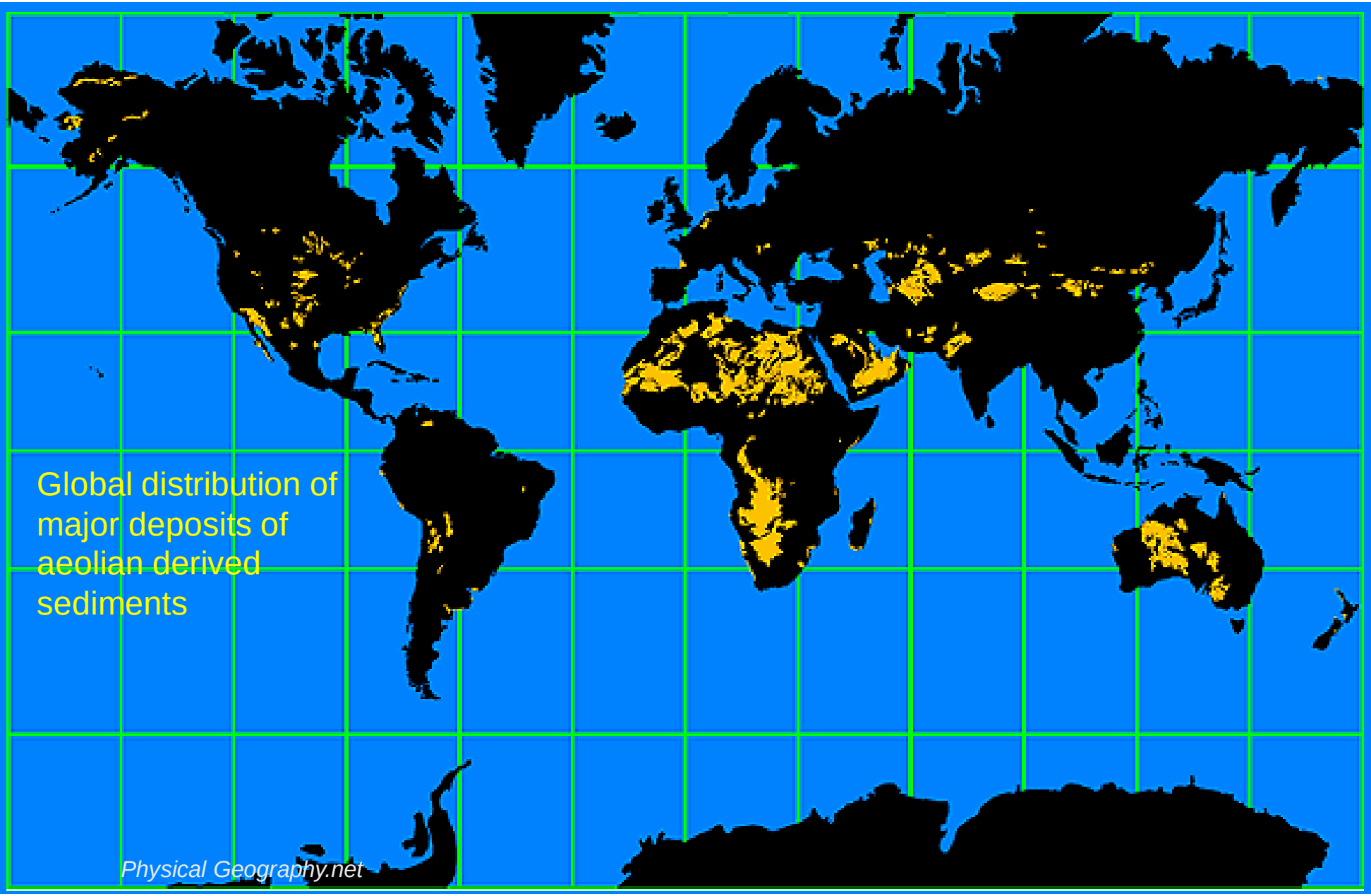
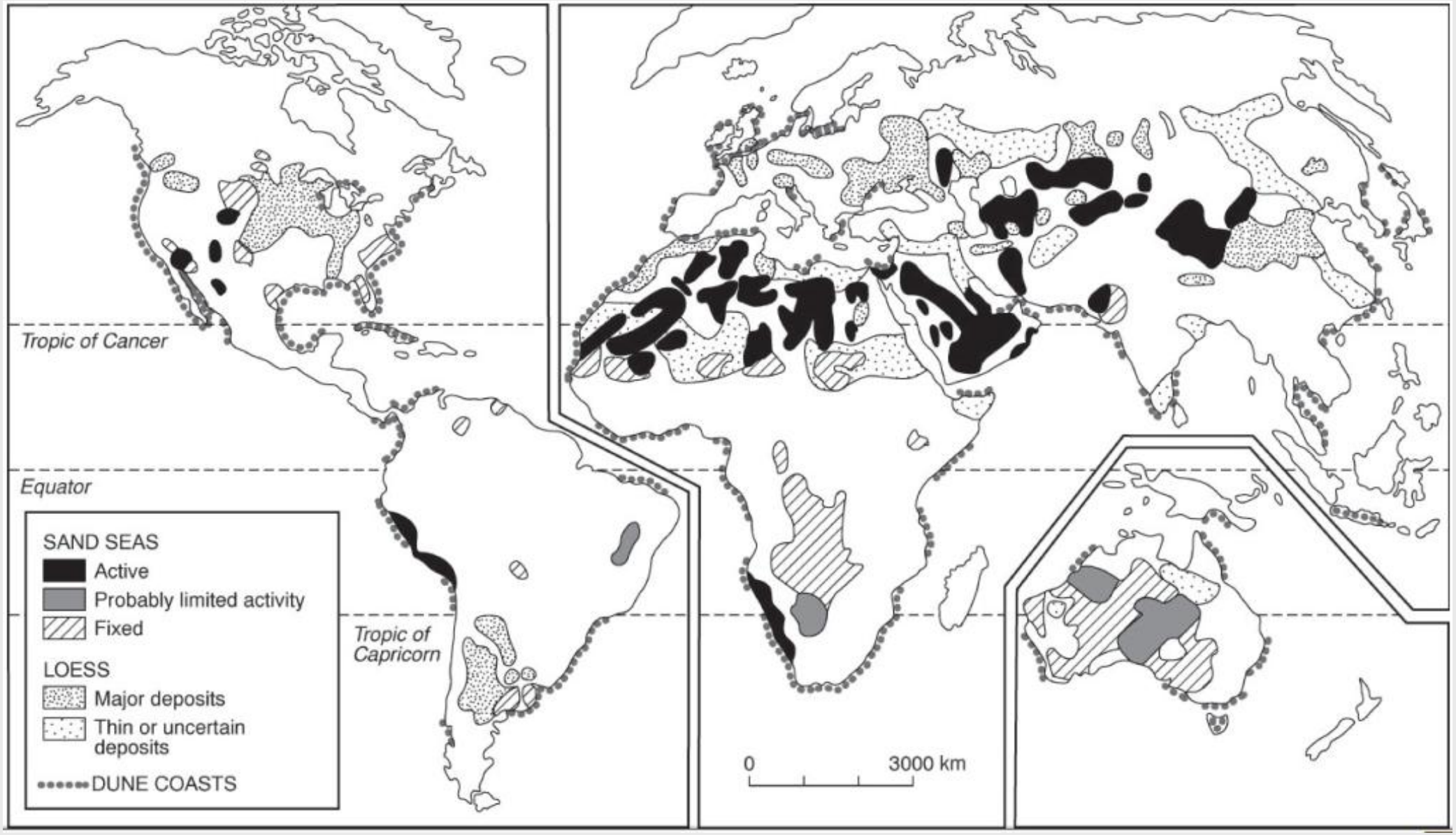
Wind action – aeolian processes

- Airflow:
  - erodes land surface,
  - transports and
  - accumulates sediment
  - Aeolian action is strongest in windy areas with dry, fine-grained sediment (+/- sand fraction) and sparse vegetation cover
    - Deserts and semi-deserts (steppes)
    - Coasts, river deltas etc. with abundant sediment source
    - Glacial / periglacial environments

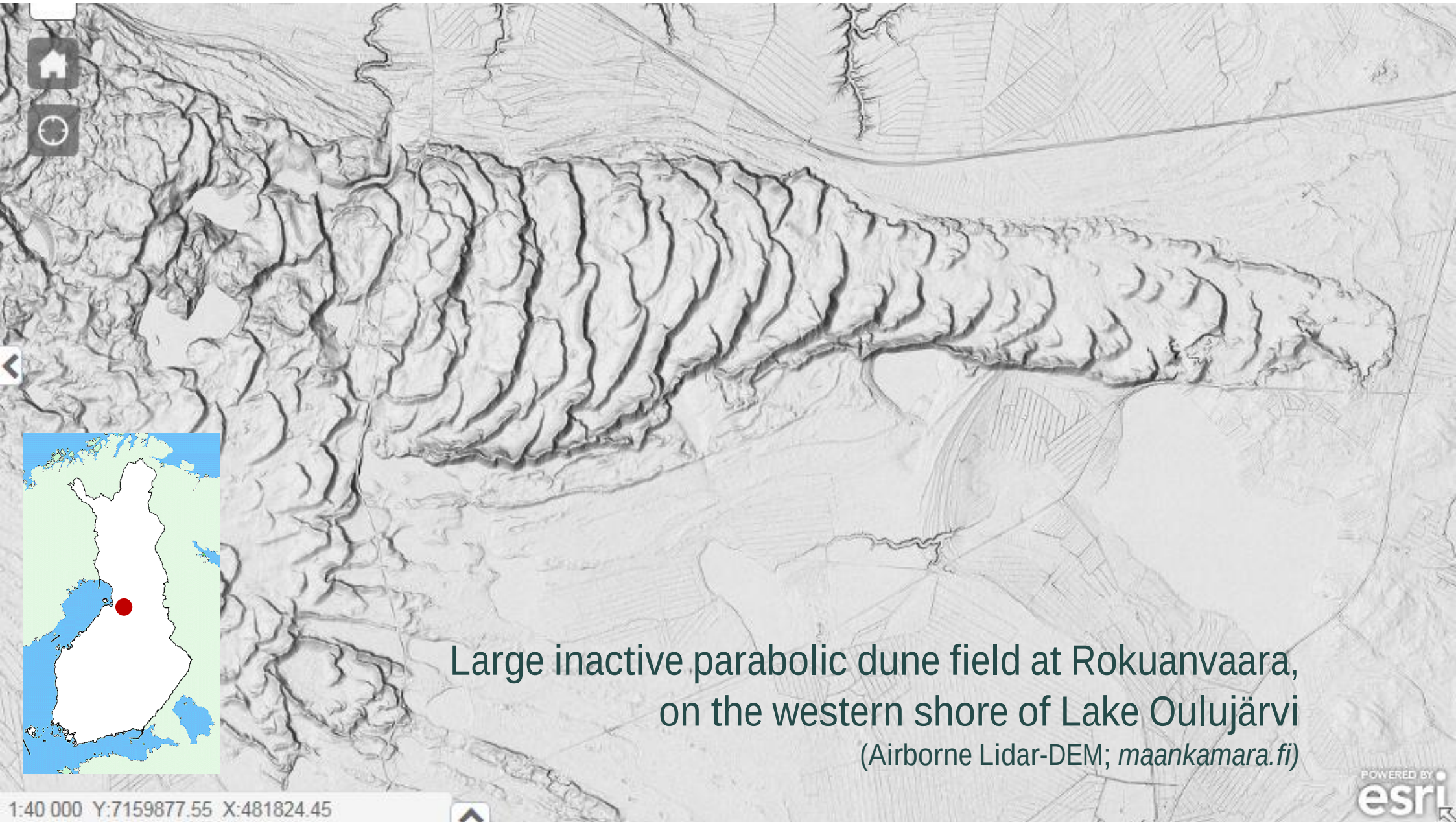

Global distribution of major deposits of aeolian derived sediments
Physical Geography.net

Global distribution of aeolian sediments, and current activity status (after Thomas, 1997). Information on dune coasts from Carter et al. (1990)



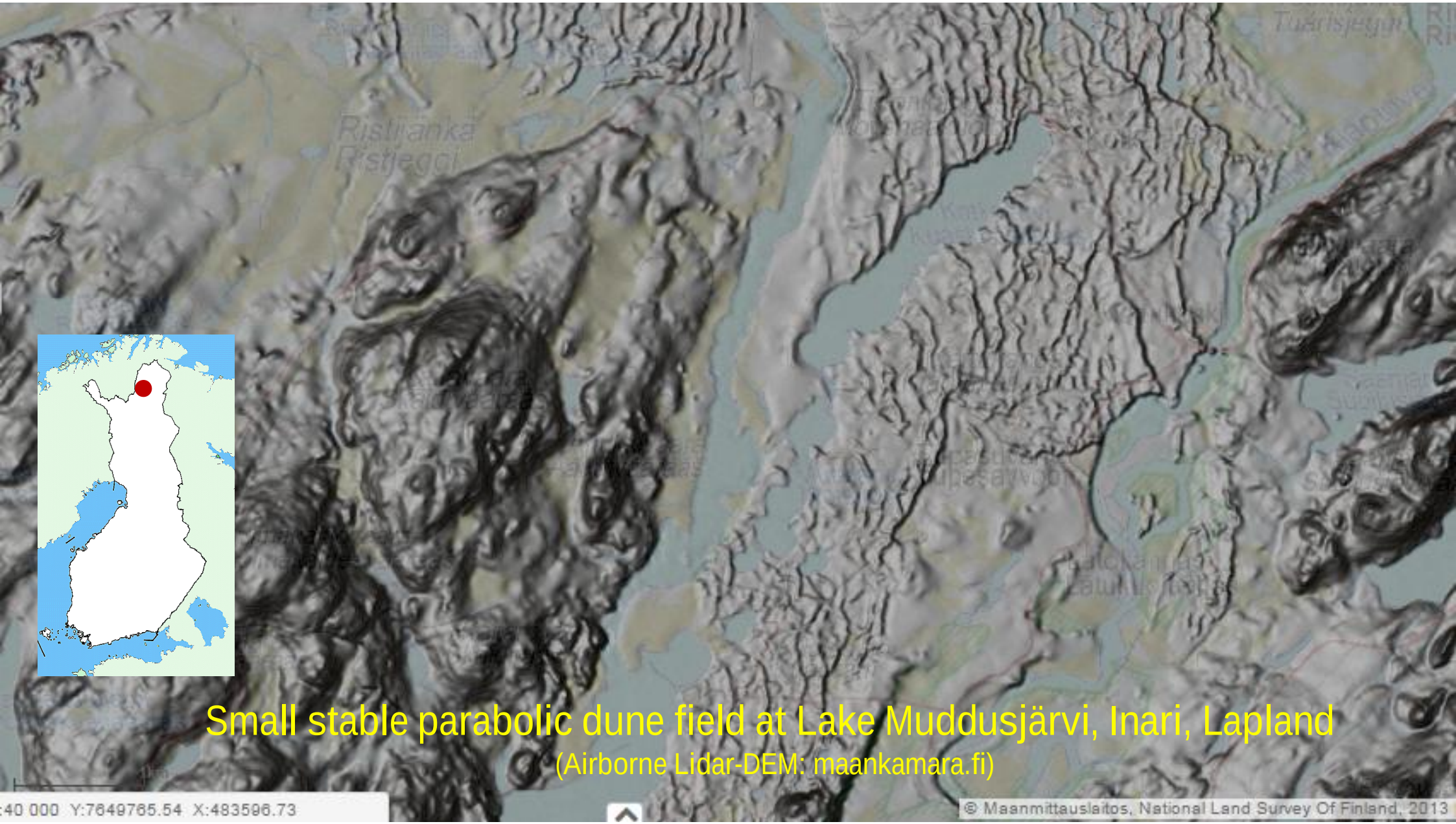
Dunes in Finland

- Three main types / regions:
  - Coastal dunes along the Baltic coast à active
  - Inland dunes adjacent to glaciofluvial deposits à stable, vegetated (forested)
  - Inland dunes in Lapland adjacent to glaciofluvial deposits near the pine forest line à partially/cyclically active



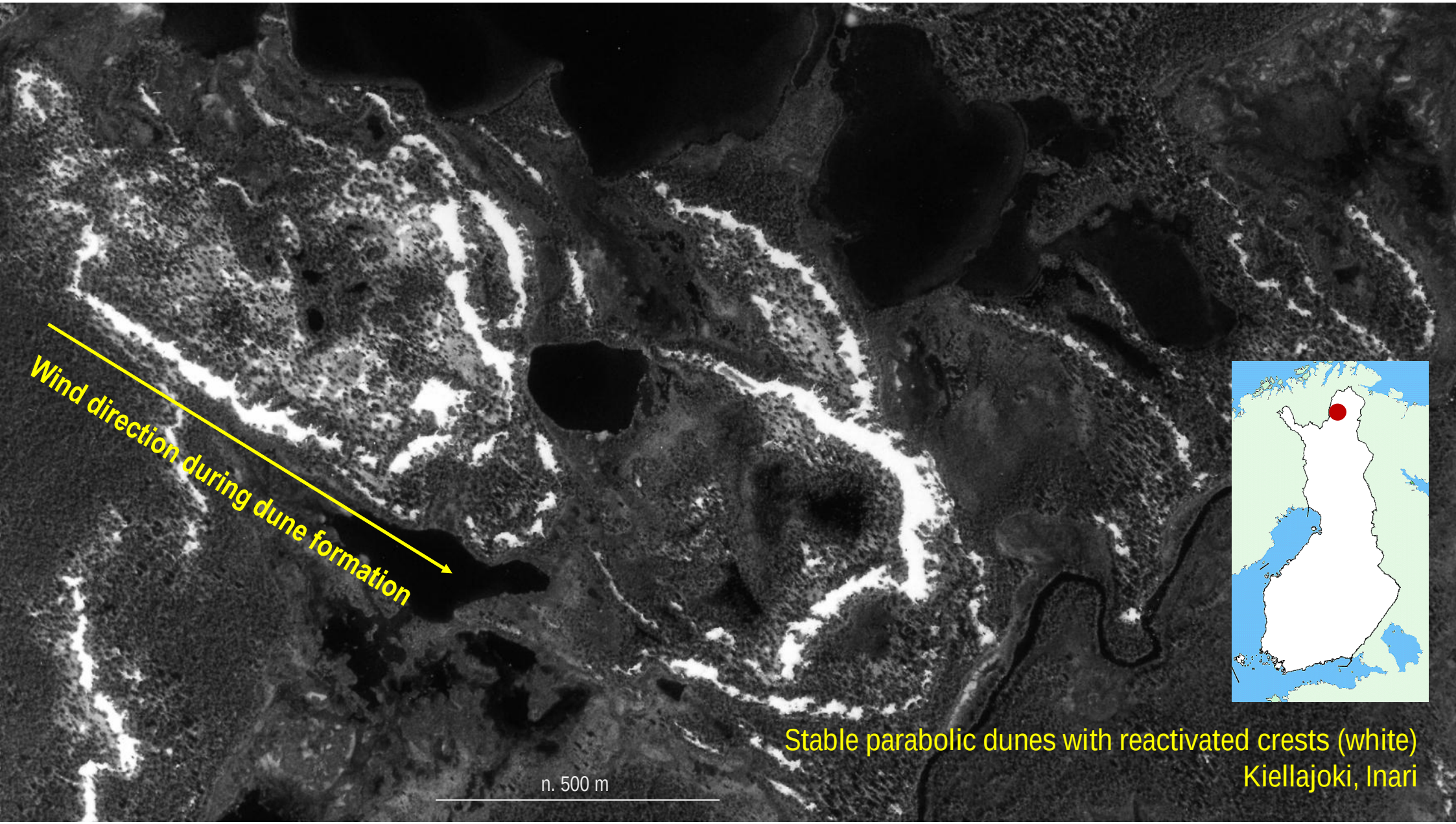
Large inactive parabolic dune field at Rokuanvaara,
on the western shore of Lake Oulujärvi

(Airborne Lidar-DEM; *maankamara.fi)*

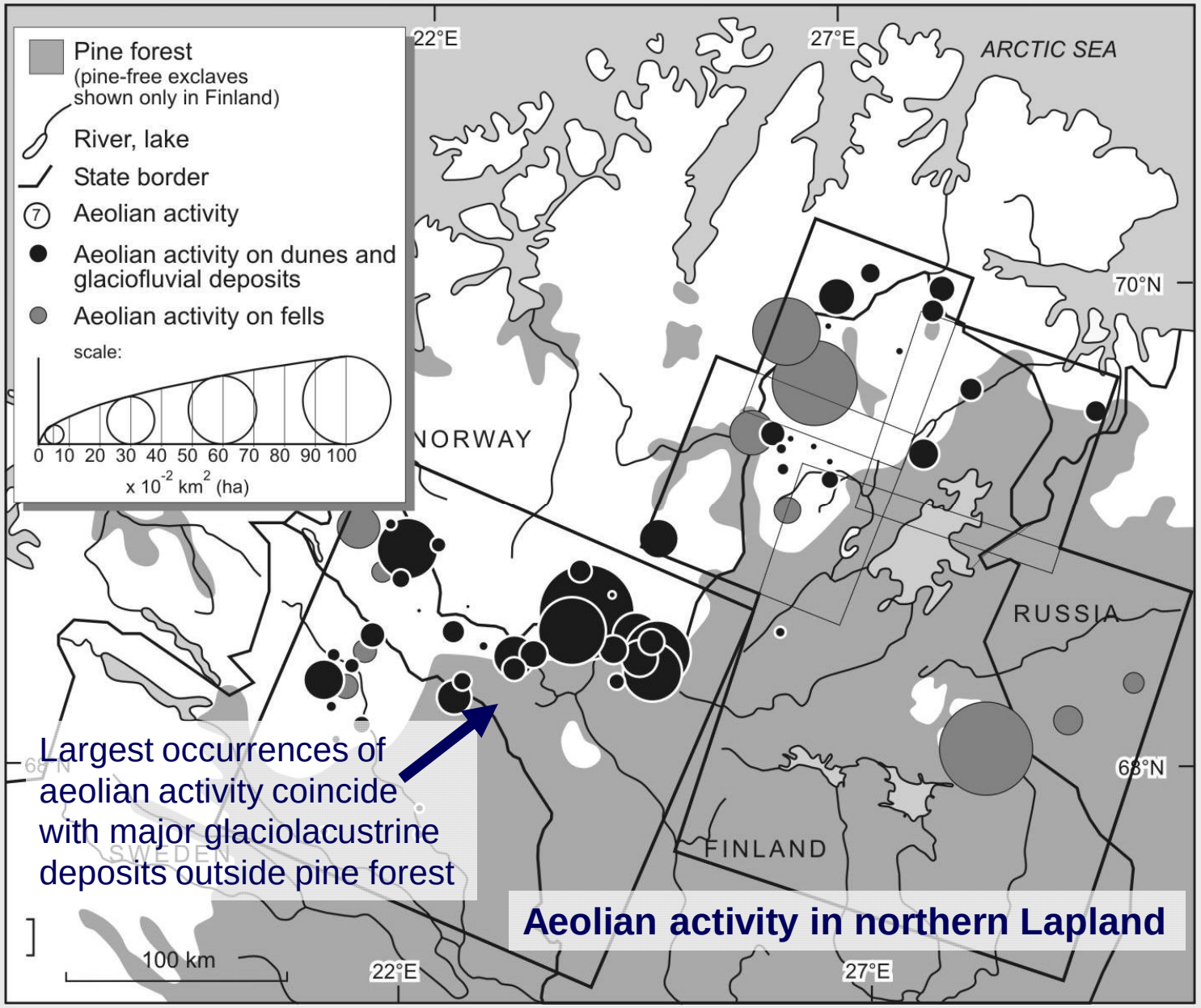


Small stable parabolic dune field at Lake Muddusjärvi, Inari, Lapland

(Airborne Lidar-DEM: maankamara.fi)

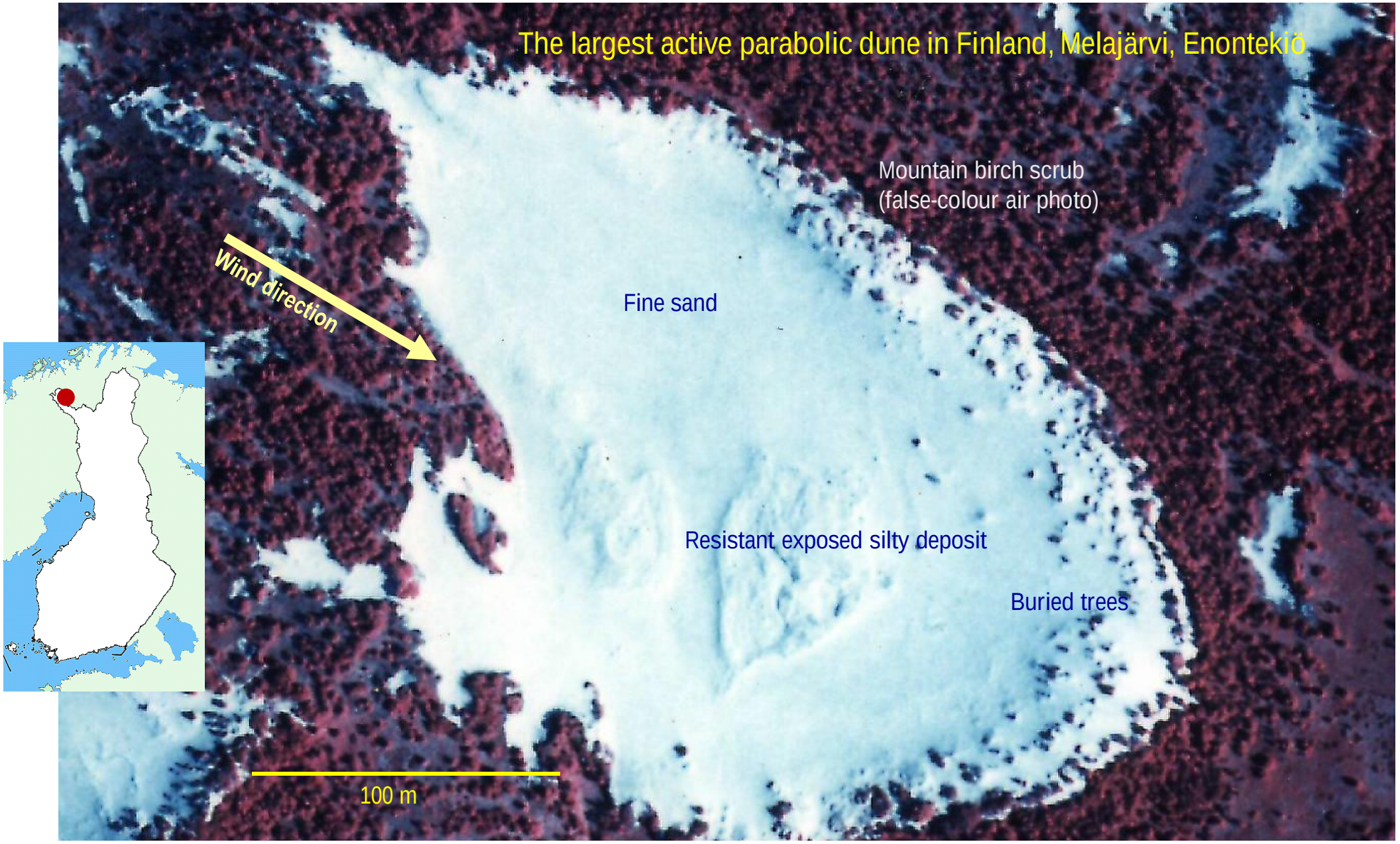


Stable parabolic dunes with reactivated crests (white)
Kiellajoki, Inari



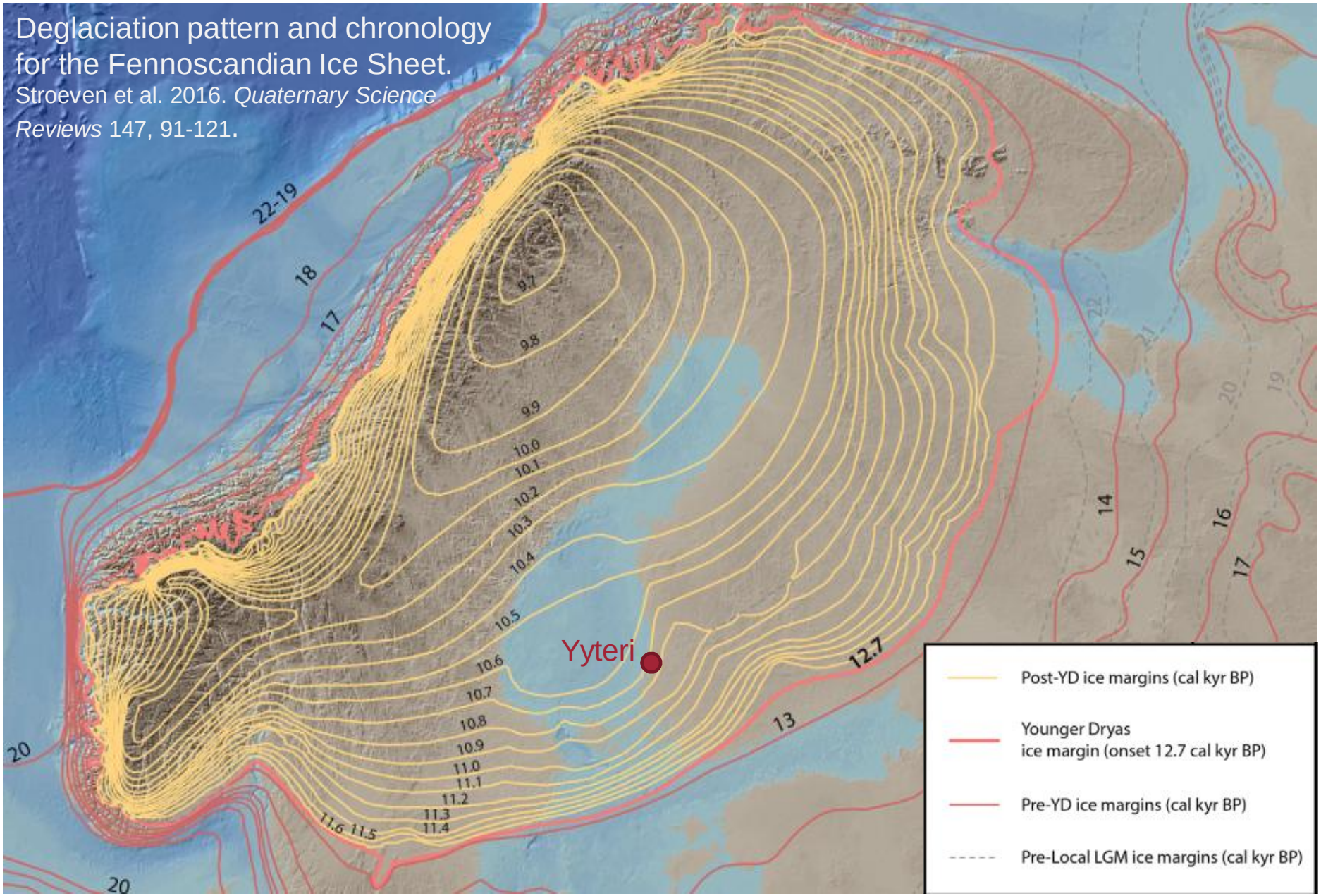
Aeolian activity in northern Lapland

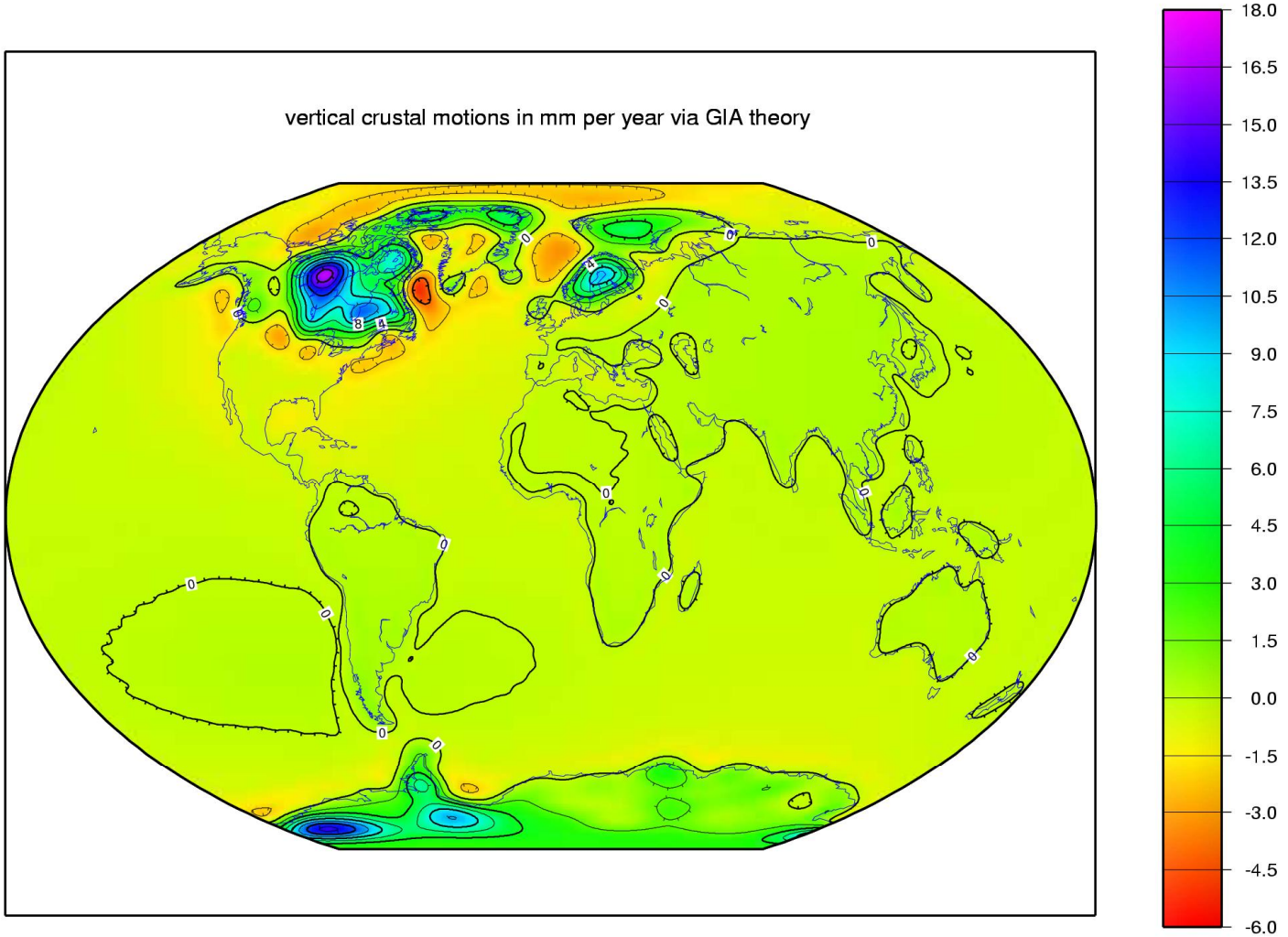
Käyhkö 1997


The largest active parabolic dune in Finland, Melajärvi, Enontekiö
Mountain birch scrub
(false-colour air photo)
Wind direction
Fine sand
Resistant exposed silty deposit
Buried trees
100 m

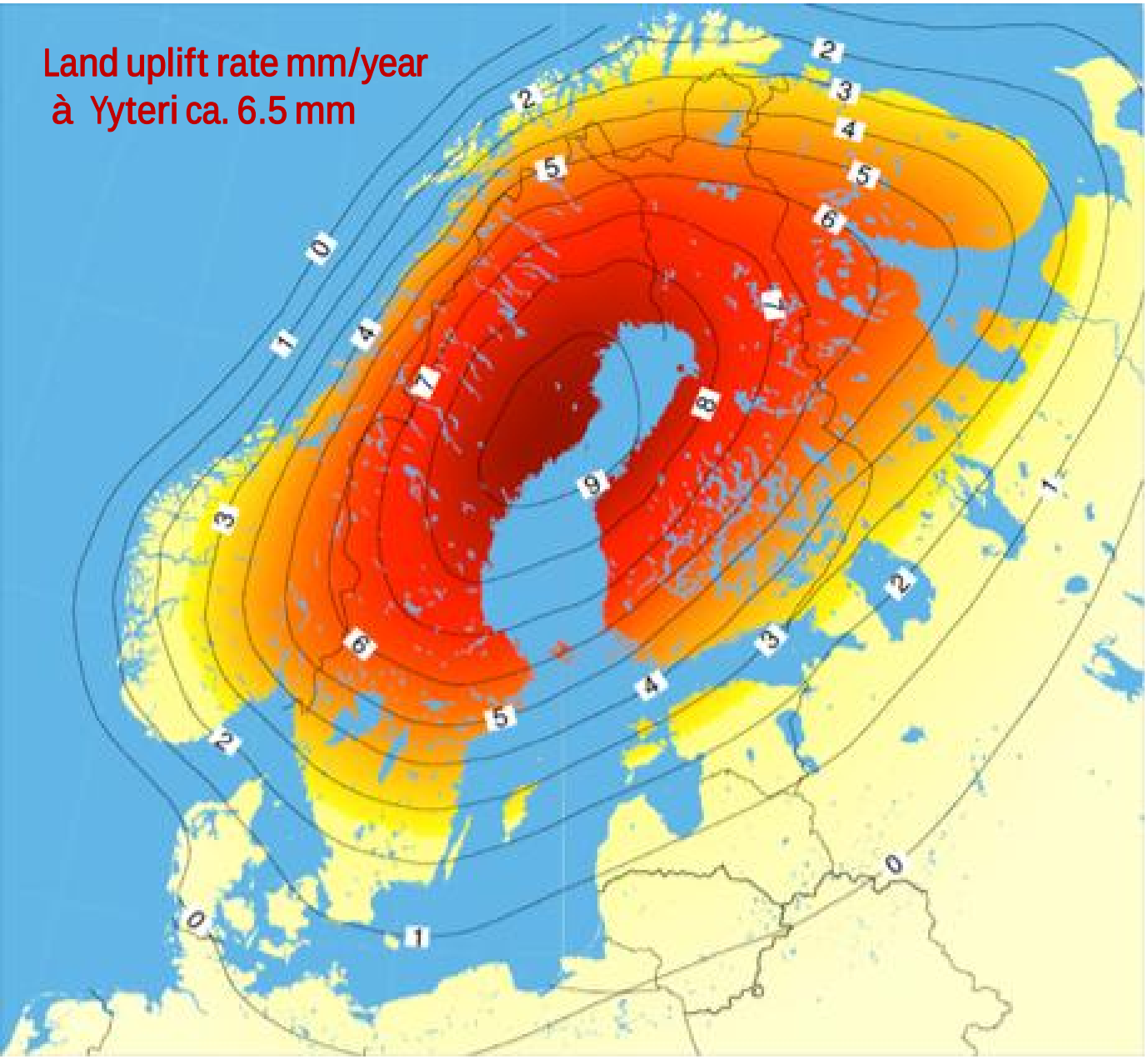
Europe during the last glaciation, approximately 20,000 to 70,000 years before present.

Finnish coastal dunes and land uplift


Deglaciation pattern and chronology for the Fennoscandian Ice Sheet.
Stroeven et al. 2016. *Quaternary Science Reviews* 147, 91-121.
Yyteri
Post-YD ice margins (cal kyr BP)
Younger Dryas ice margin (onset 12.7 cal kyr BP)
Pre-YD ice margins (cal kyr BP)
Pre-Local LGM ice margins (cal kyr BP)



Glacial isostatic uplift (GIA), or Postglacial rebound (PGR)

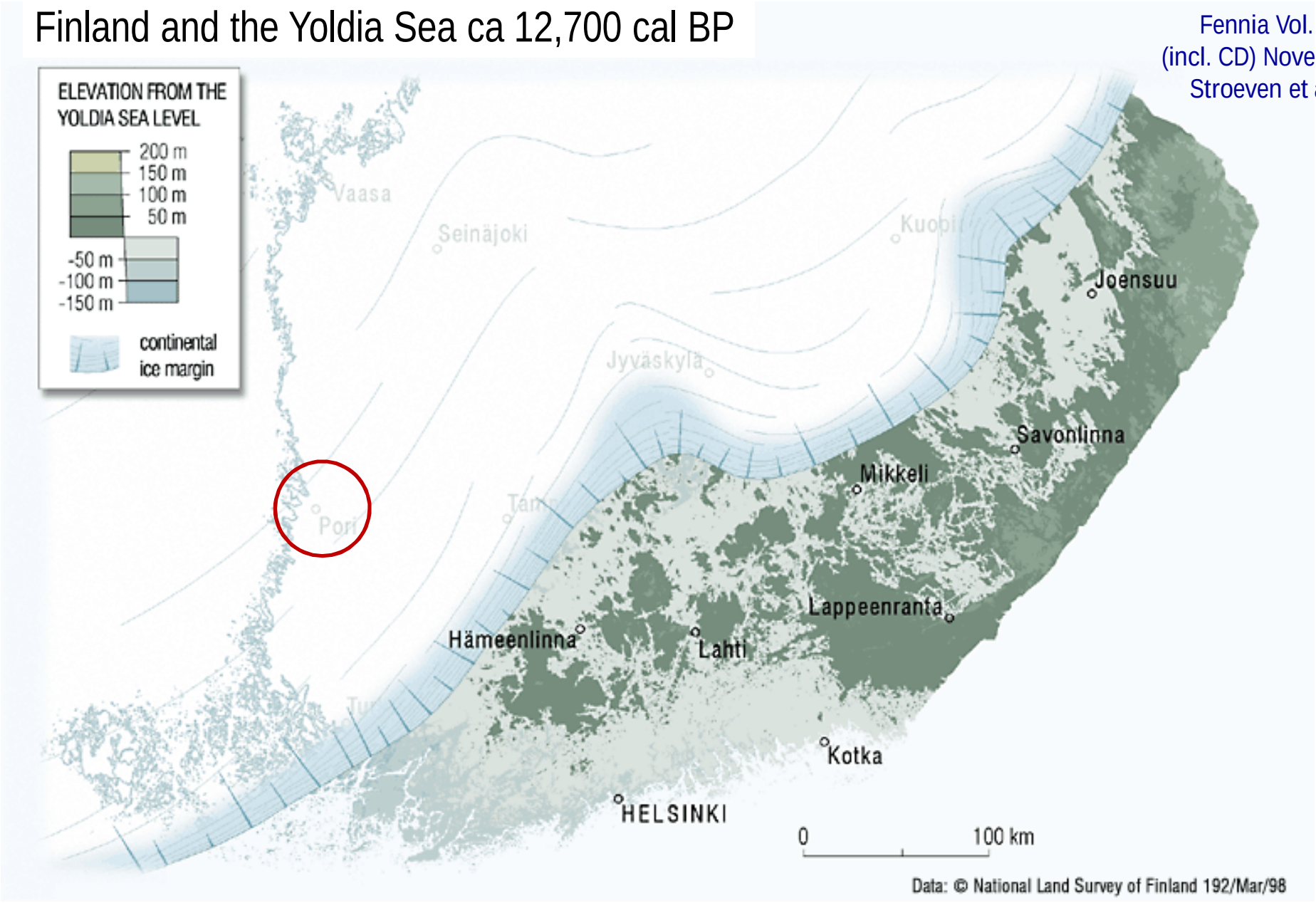

Land uplift rate mm/year
à Yyteri ca. 6.5 mm


Supra- and subaquatic regions
in Finland

https://www.youtube.com/watch?time_continue=11&v=Y753x2Xb4gY

Finland and the Yoldia Sea ca 12,700 cal BP

Fennia Vol. 180, No. 1–2
(incl. CD) November 2002 &
Stroeven et al. QSR 2016




Porin rannikko, meren pinta 4.0 m korkeammalla kuin nykyisin
Pohjakartta © Maanmittauslaitos, MML_laserkeilaus_2m lupa nro 13/MML/09
Värien merkitys
Muinaismeri
0 - 5 m
5 - 10 m
10 - 15 m
15 - 20 m
20 - 25 m
25 - 30 m
30 - 35 m
35 - 40 m
40 - 45 m
45 - 50 m
50 - >55 m
1400 AD
Pori
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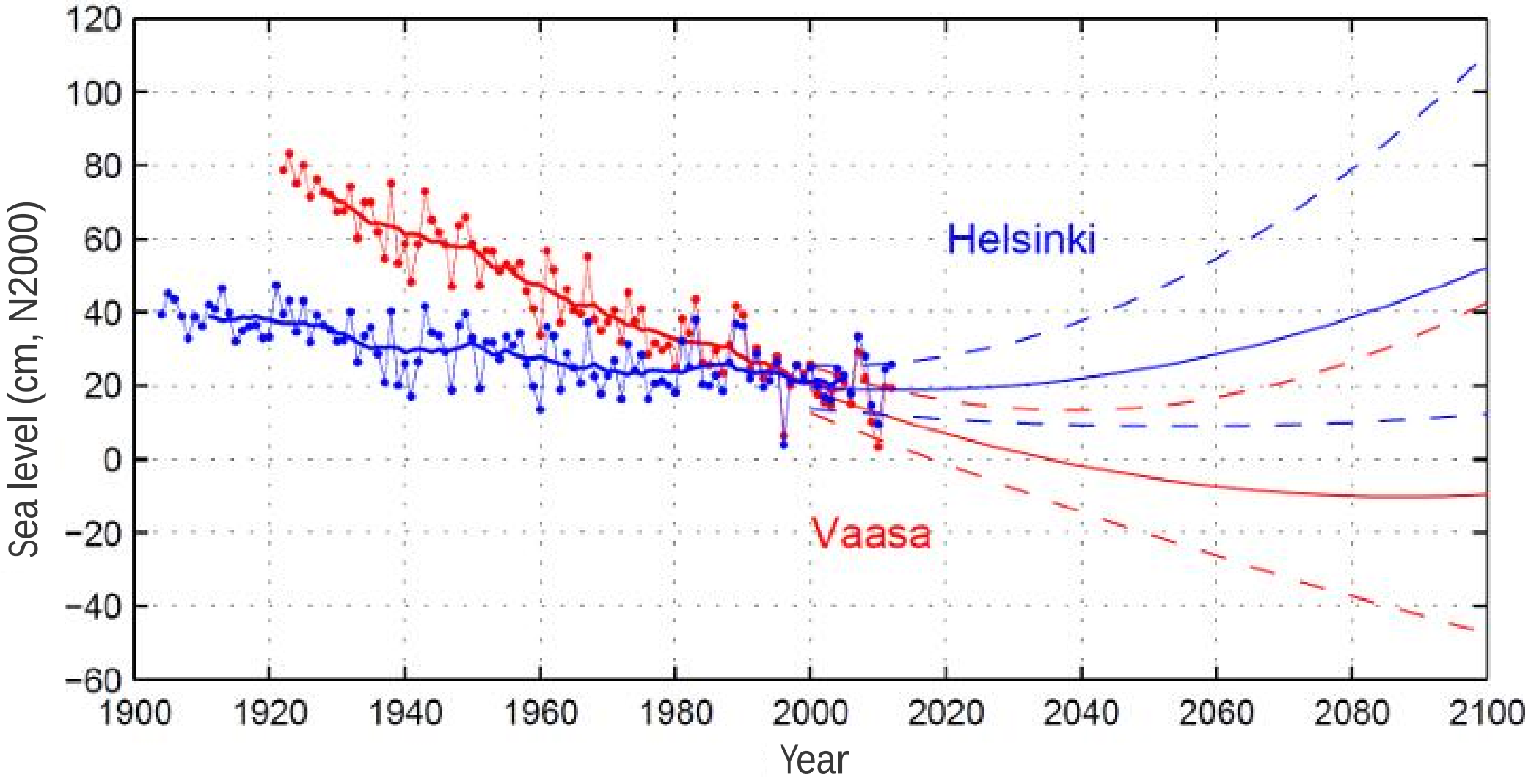
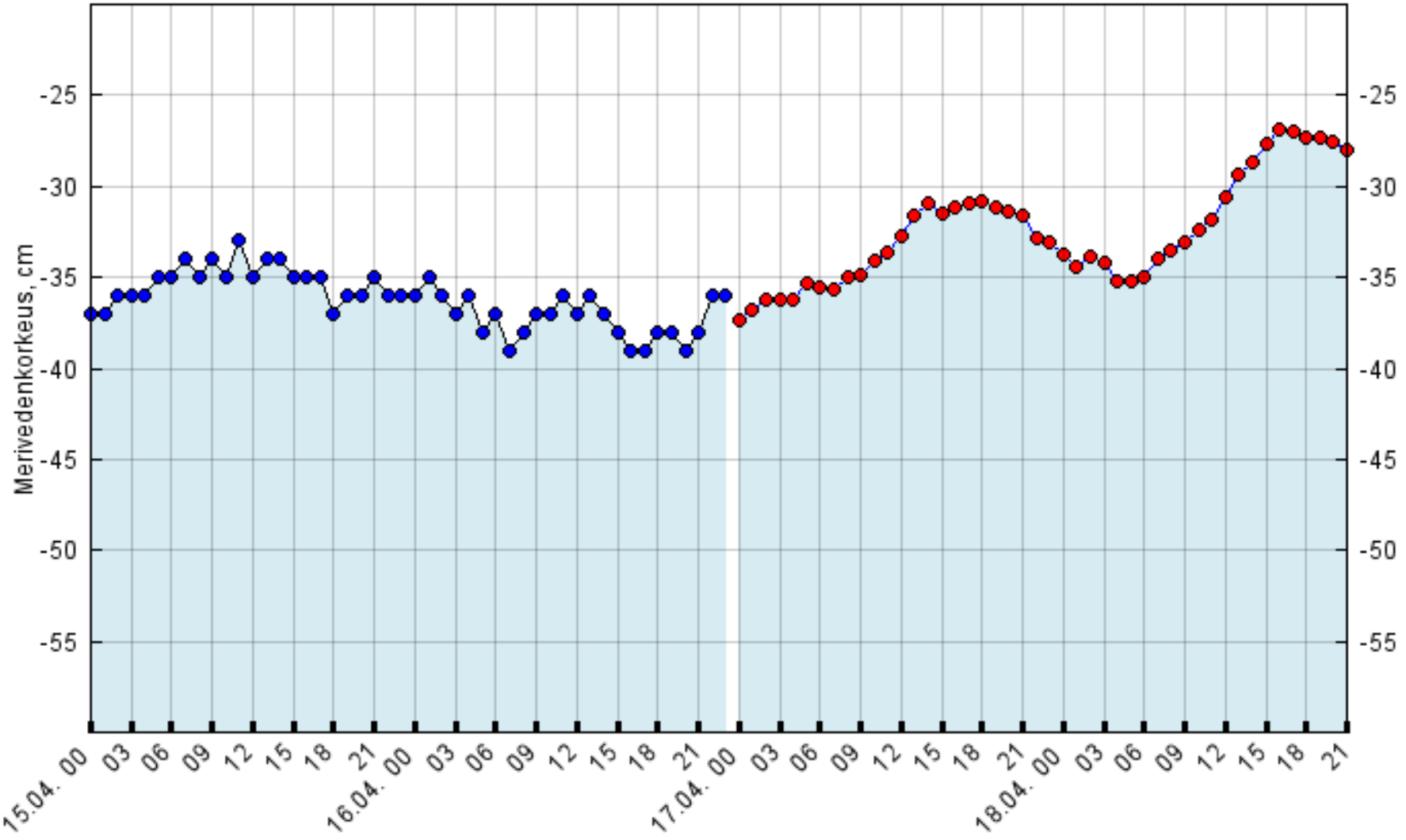
2.5
5
10 km
GTK



Finnish Met. Inst. FMI: http://ilmatieteenlaitos.fi/merenpinnan-nousu-suomen-rannikolla

Mäntyluoto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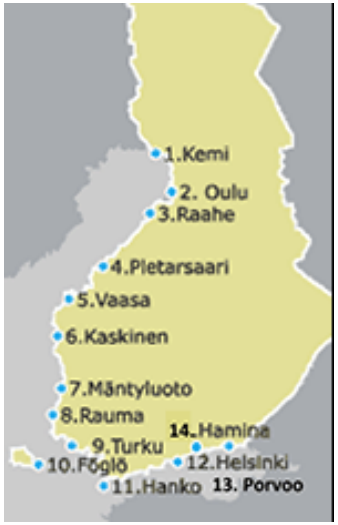
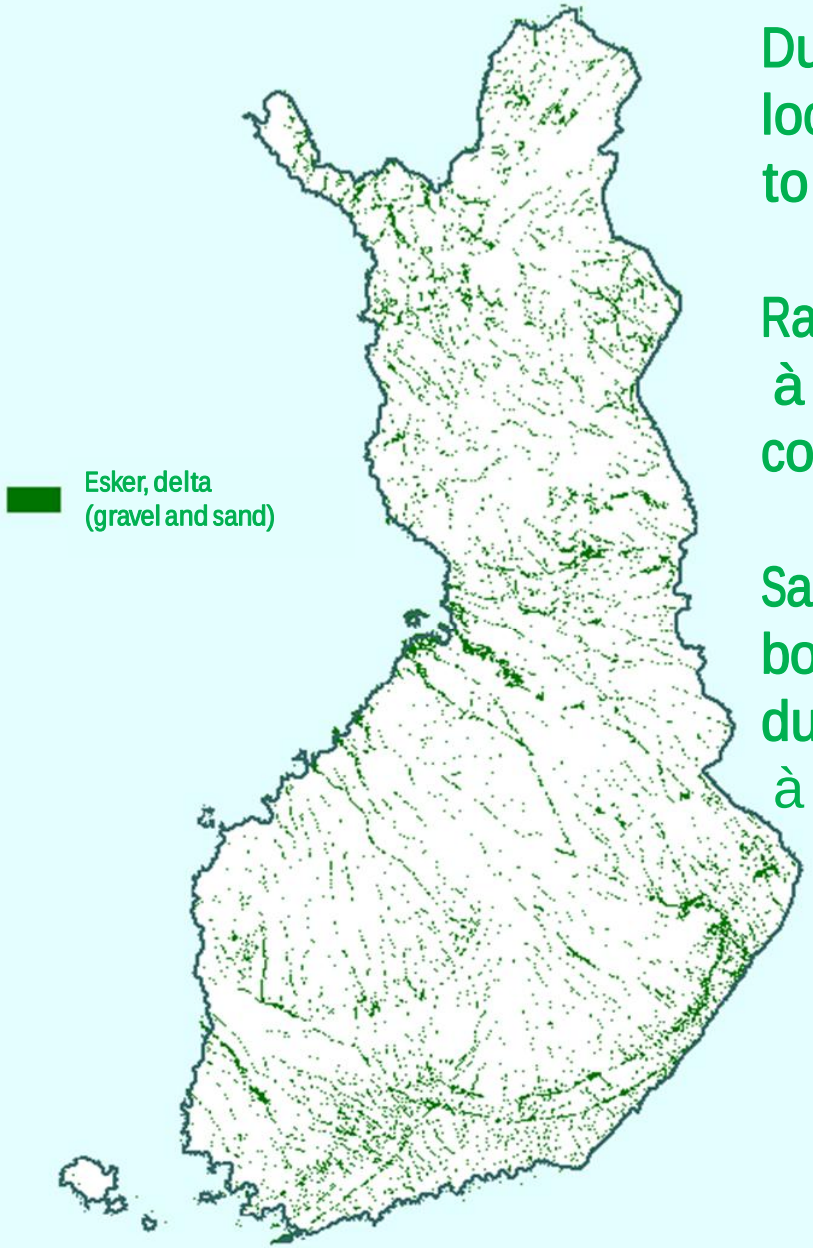
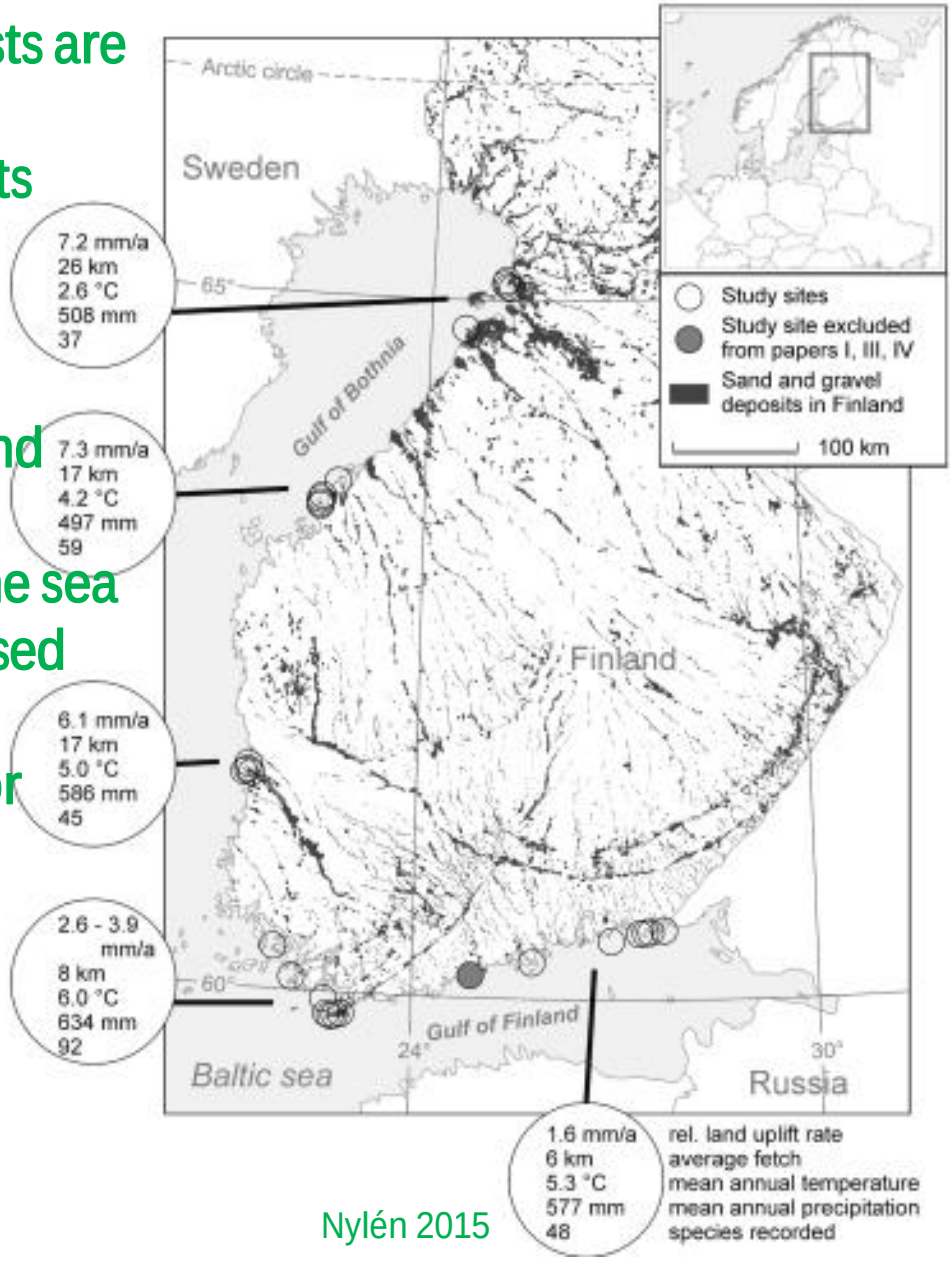

1.Kemi
2. Oulu
3.Raahe
4.Pietarsaari
5.Vaasa
6.Kaskinen
7.Mäntyluoto
8.Rauma
9.Turku
10.Föglö
11.Hanko
12.Helsinki
13. Porvoo
14.Hamina



Dunes on Finnish coasts are located adjacent to glaciofluvial deposits

Rather rare feature
à only 1300 ha of coastal dunes in Finland

Sandy sediments of the sea bottom become exposed due to land uplift
à Sediment source for coastal dunes



Nylén 2015

Sediment transport

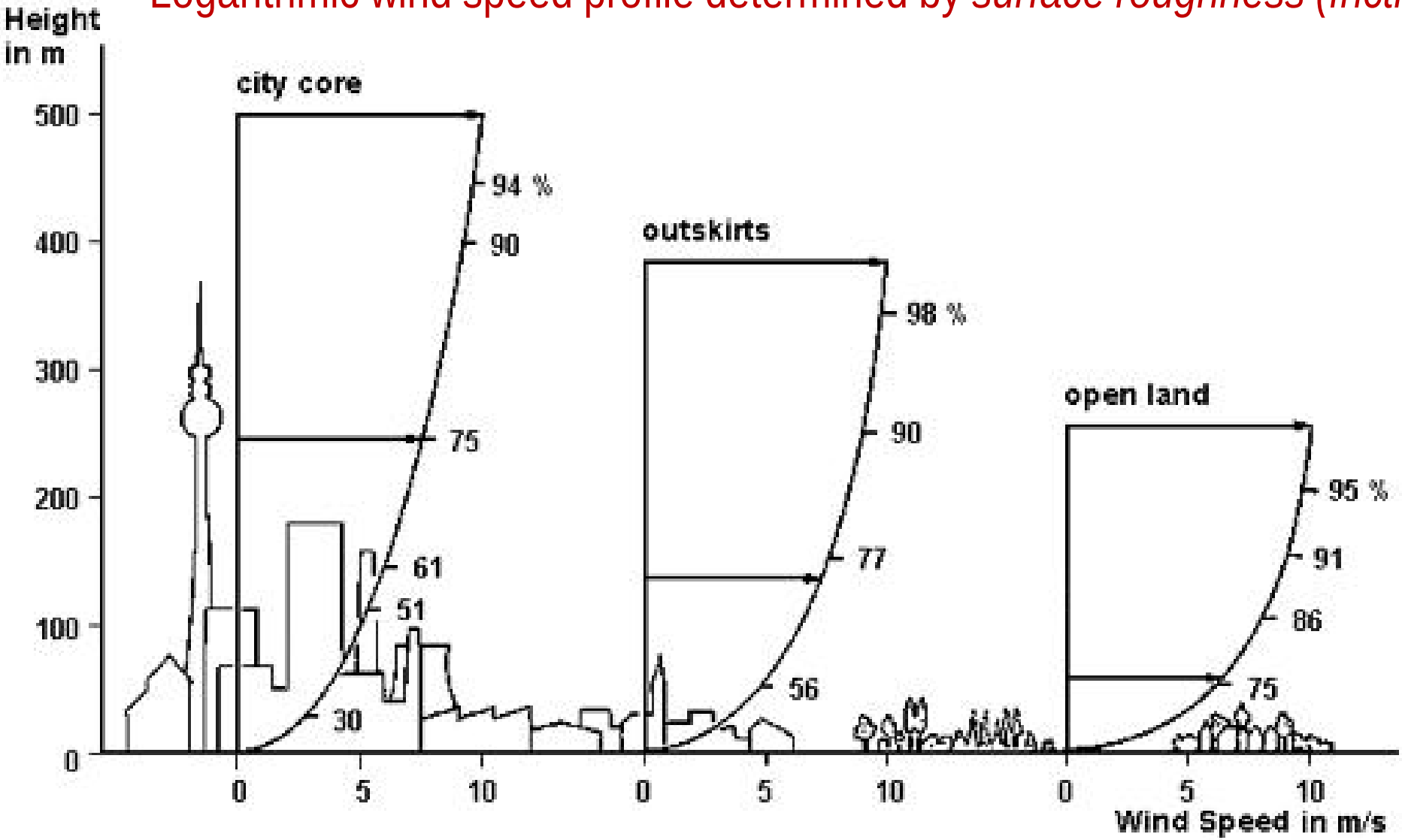
Key factors:

1) Airflow – *atmospheric boundary layer*
2) Forces that affect sand grain
3) Threshold shear velocity
4) Other factors that affect particle entrainment (e.g. moisture content, salinity)
5) Particle flight paths and chain reactions caused by bouncing particles

Aeolian processes (1)

- Airflow properties:
  - Low viscosity (+15°C: n = 1.45 ´ 10^{-5} m^{-2} s^{-1})
  - Low density (r = 1.23 kg m^{-3})
  - High speed –> turbulent flow
  - Reynolds number determines the threshold between laminar and turbulent flow
    - *Re* = *LU*/n,
      - where L is length (here: diameter), U speed, and n viscosity
  - Re > 6000 = turbulent flow; in practice > 0.1 m/s speed
  - Wind speed 0-height: d/30, where d is particle size
  - Logarithmic velocity gradient

Logarithmic wind speed profile determined by *surface roughness (friction)*



Aeolian processes (2)

- Wind speed at sand surface à Shear stress u_* *(”u-star”) (”wind stress”)*

$$u_* = U/[(1/\kappa)\ln(z/d) + C],$$

where
U is wind speed (m/s) at elevation z (m),
d is sediment grain size (m),
κ [kappa] is von Kármán constant (0,4),
C is empirical constant 8,48

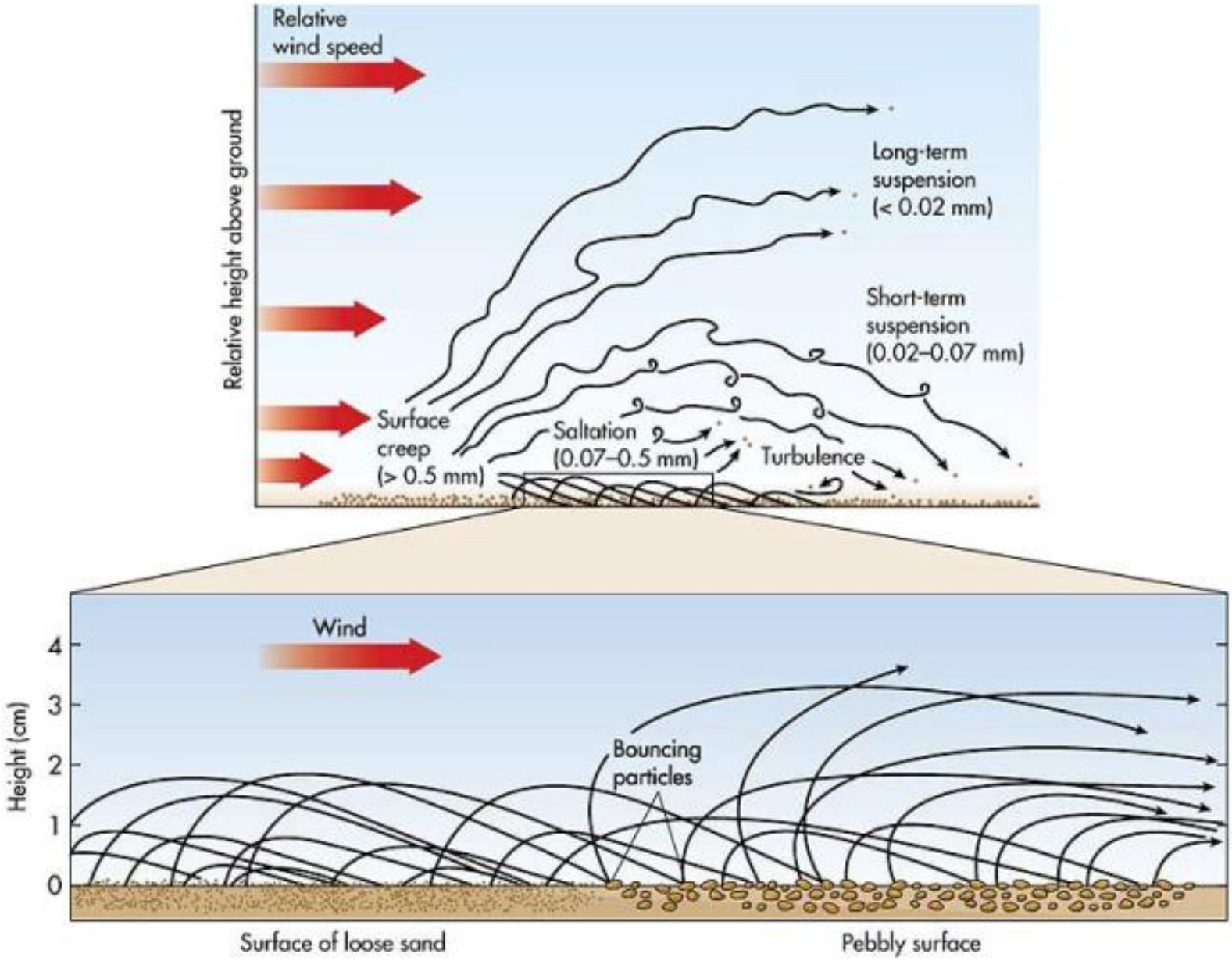
When does sand start to move?

à threshold wind speed for sand (Bagnold 1941)

$$u_{*t} = A\sqrt{\frac{\sigma - \rho}{\rho} g d}$$

where

- A is constant 0.1 (when d > 80 µm)
- σ is particle density
- ρ is air density
- g is acceleration of gravity
- d is particle diameter


Relative wind speed
Relative height above ground
Long-term suspension (< 0.02 mm)
Short-term suspension (0.02–0.07 mm)
Surface creep (> 0.5 mm)
Saltation (0.07–0.5 mm)
Turbulence
Wind
Height (cm)
4
3
2
1
0
Bouncing particles
Surface of loose sand
Pebbly surface

How much sand is moved?

à transport amount (Bagnold 1941)

$$q = C\sqrt{\frac{d}{D}}\frac{\rho}{g}\,u_*^3,$$

where

q is mass of transported sand per gate width and time

C is constant (between 1.5 and 3.5, for ”normal dune sand” 1.8)

ρ is air density

g is acceleration of gravity and

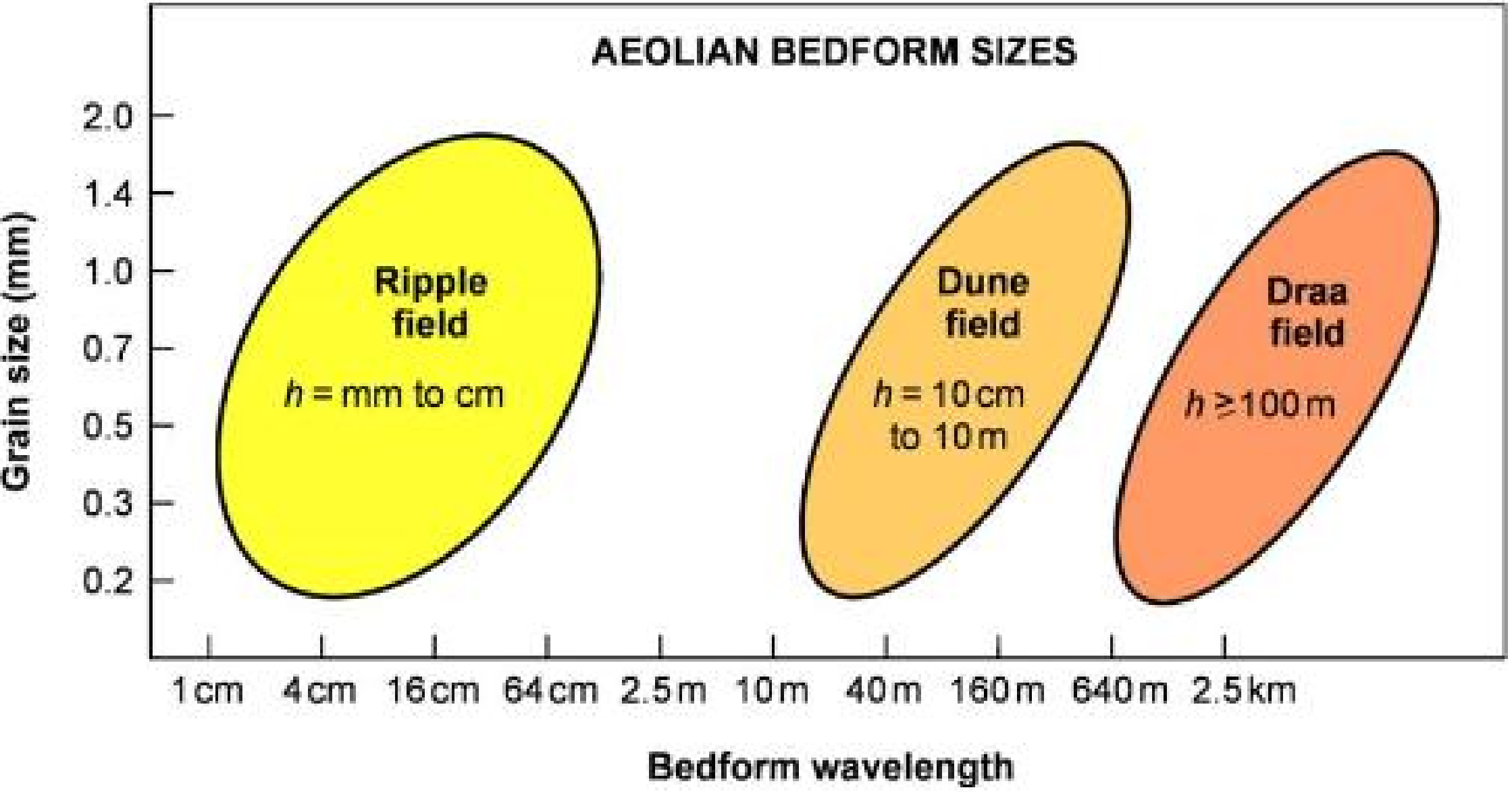
d is mean particle size (=d50)

D is particle standard diameter of 250 mm

u_* is shear stress

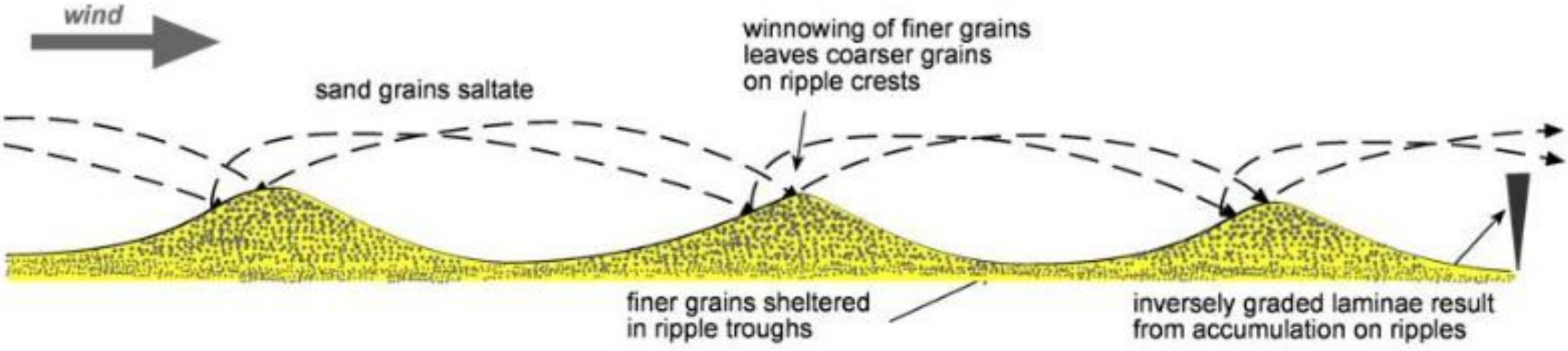
Sand dunes

- A bedform of loose sand
- Typically quartz grains (resistant), also other minerals
- ca. 200 µm diameter
- three scales:
  - *ripples*; centimetres – desimetres
  - *dunes*; tens of metres – hundreds of metres
  - draa-formations; hundreds of meters - kilometers
- these formations do not grow from one form to another, but occur simultaneously (overlapping)

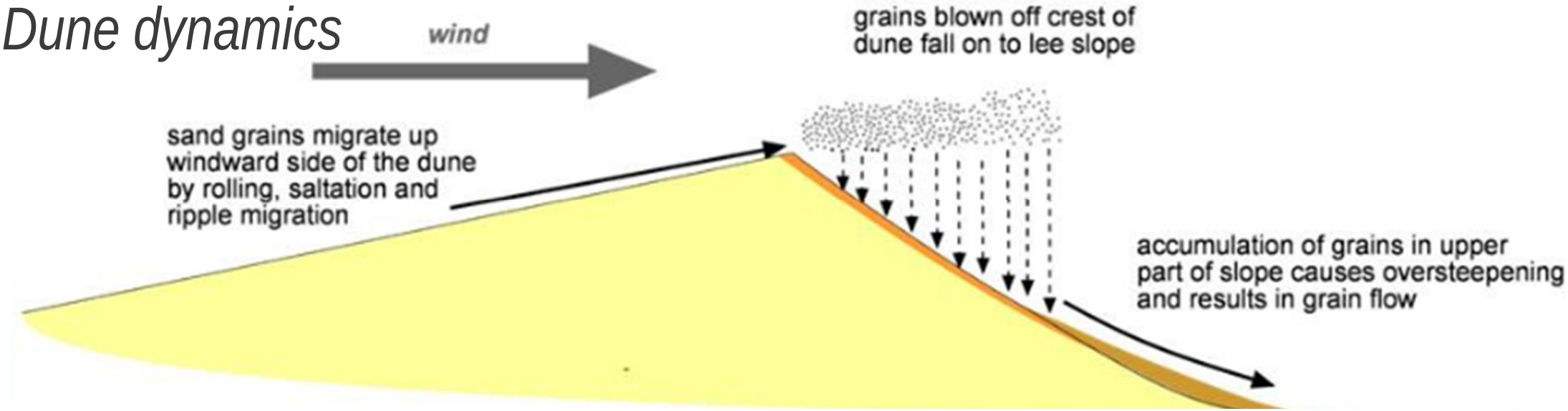


Gary Nichols: Sedimentology & Stratigraphy. Wiley.

Ripple dynamics



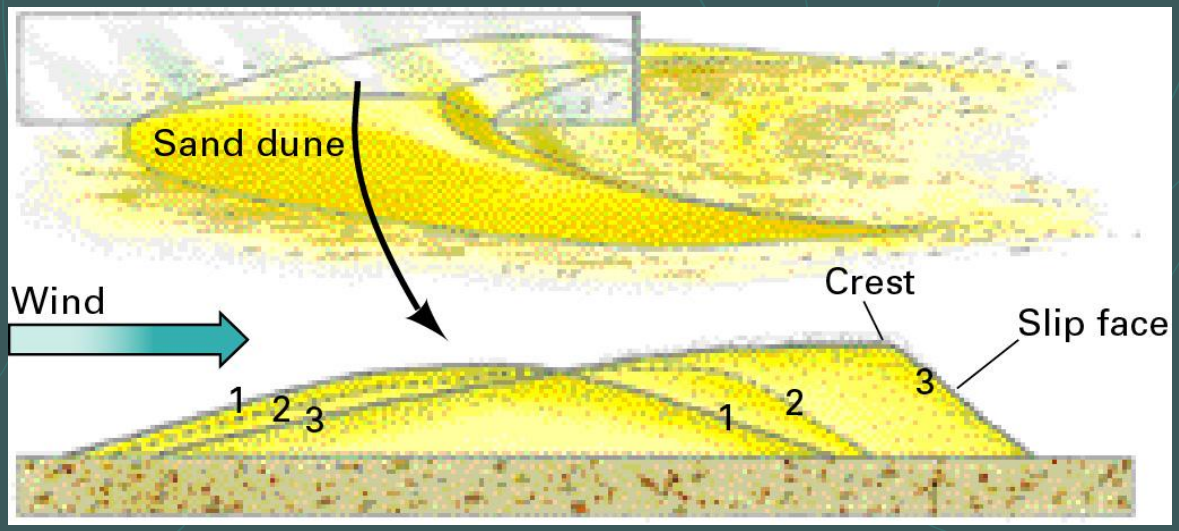
Dune dynamics



Sand Dune Development

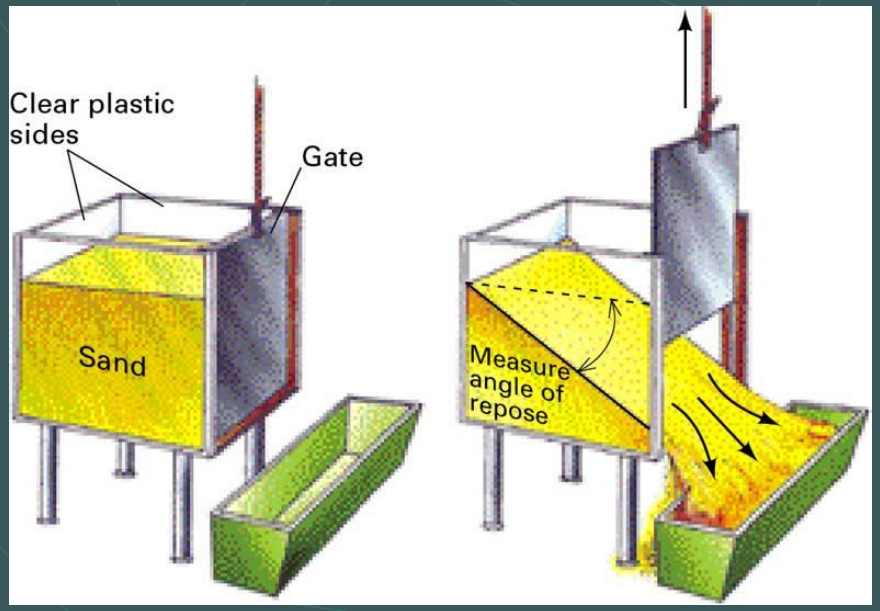
- Starts from an embryo dune *(nebkha)*
- accumulation is triggered by an obstacle (grass tussock, rock, hump etc.) that causes turbulence
- Many dunes migrate gradually downwind

- Sand grain climbs up the *stoss slope*, over the *dune crest* and falls down on the *slip face (=lee face)*, which has a typical angle of repose (ca. 30 °)

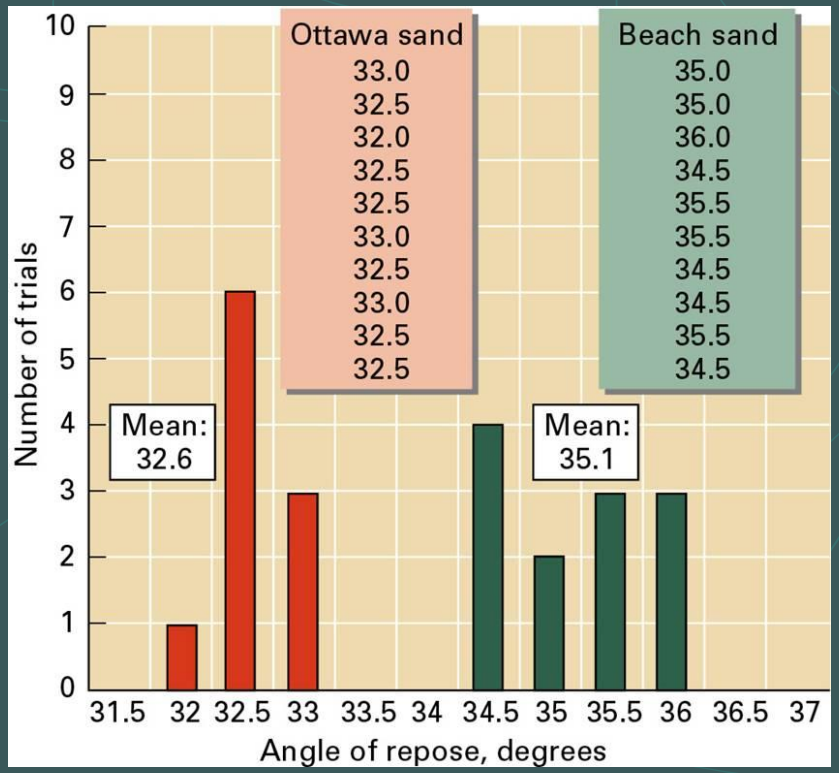


*Angle of repose (*lepokulma *in Finnish)*

- The steepest possible angle for a sediment (in the absence of vegetation, excessive moisture etc.)
- Measurement of the angle of repose:



- Different sediments have slightly different angles of repose:



Coastal dunes system in Yyteri – four dune types from the beach towards inland

- Shifting embryo dunes deposited on the back beach with the help of *Leymus* (sea lyme grass) and *Honkenya* (sea sandwort)
- Shifting foredunes covered with *Leymus* (”white dunes”)
- Fixed coastal dunes with grasses, herbs, mosses, lichens (”grey dunes”)
- Forested dunes with *Pinus* (Scots pine) on stoss slopes and deciduous species *(Betula, Sorbus, Alnus)* on steep slipfaces

Turun yliopisto
University of Turku

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

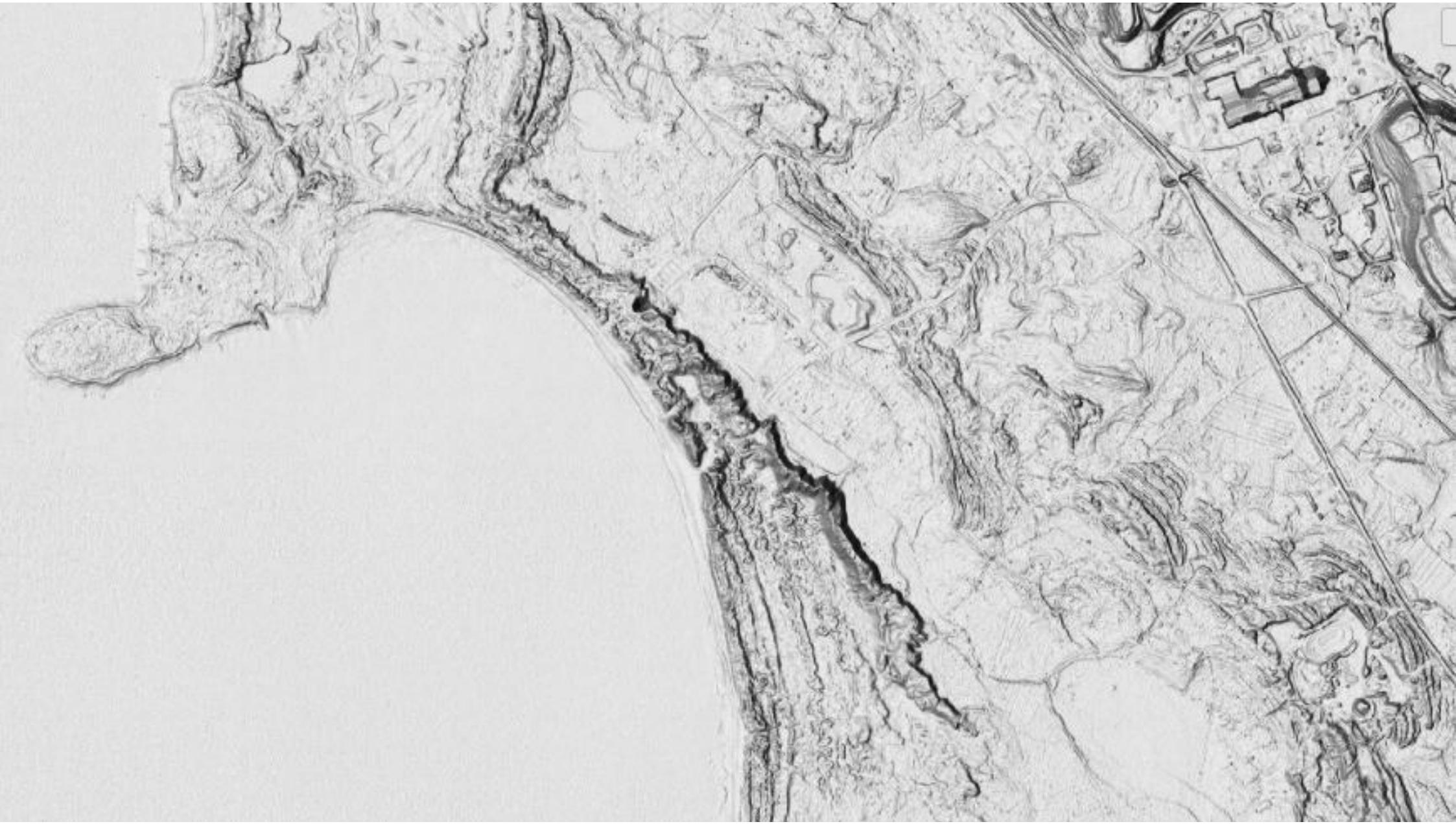
2. COASTAL SAND DUNES AND INLAND DUNES

21. Sea dunes of the Atlantic, North Sea and Baltic coasts

The dune types found in Yyteri are marked with red (approx. area in ha)

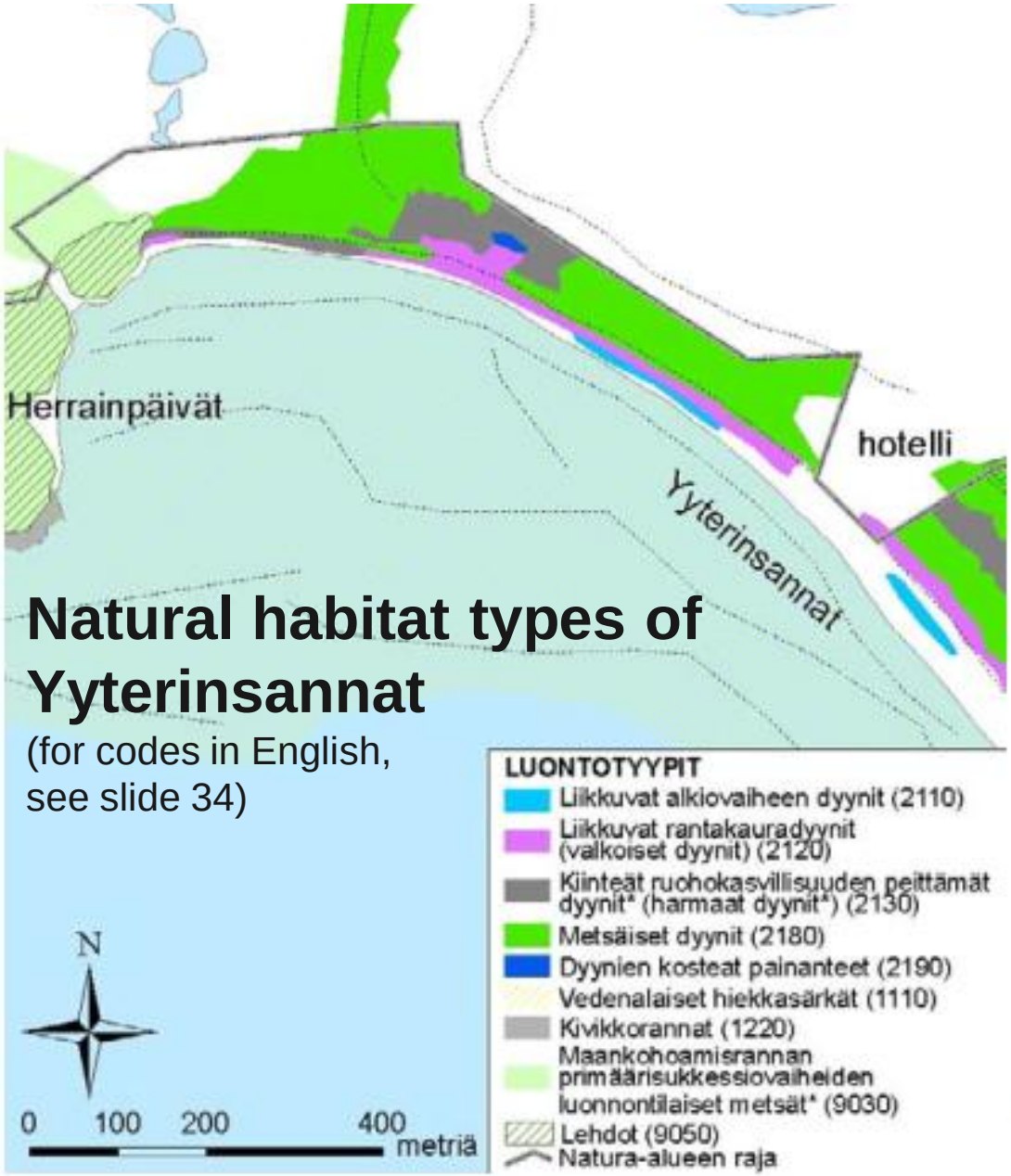
- **2110** Embryonic shifting dunes (2 ha)
- **2120** Shifting dunes along the shoreline with Ammophila arenaria ('white dunes') (10 ha)
- **2130** * Fixed coastal dunes with herbaceous vegetation ('grey dunes') (25 ha)
- **2140** * Decalcified fixed dunes with Empetrum nigrum
- **2150** * Atlantic decalcified fixed dunes (Calluno-Ulicetea)
- **2160** Dunes with Hippophaë rhamnoides
- **2170** Dunes with Salix repens ssp. argentea (Salicion arenariae)
- **2180** Wooded dunes of the Atlantic, Continental and Boreal region (55 ha)
- **2190** Humid dune slacks (0.4 ha)
- **21A0** Machairs (* in Ireland)

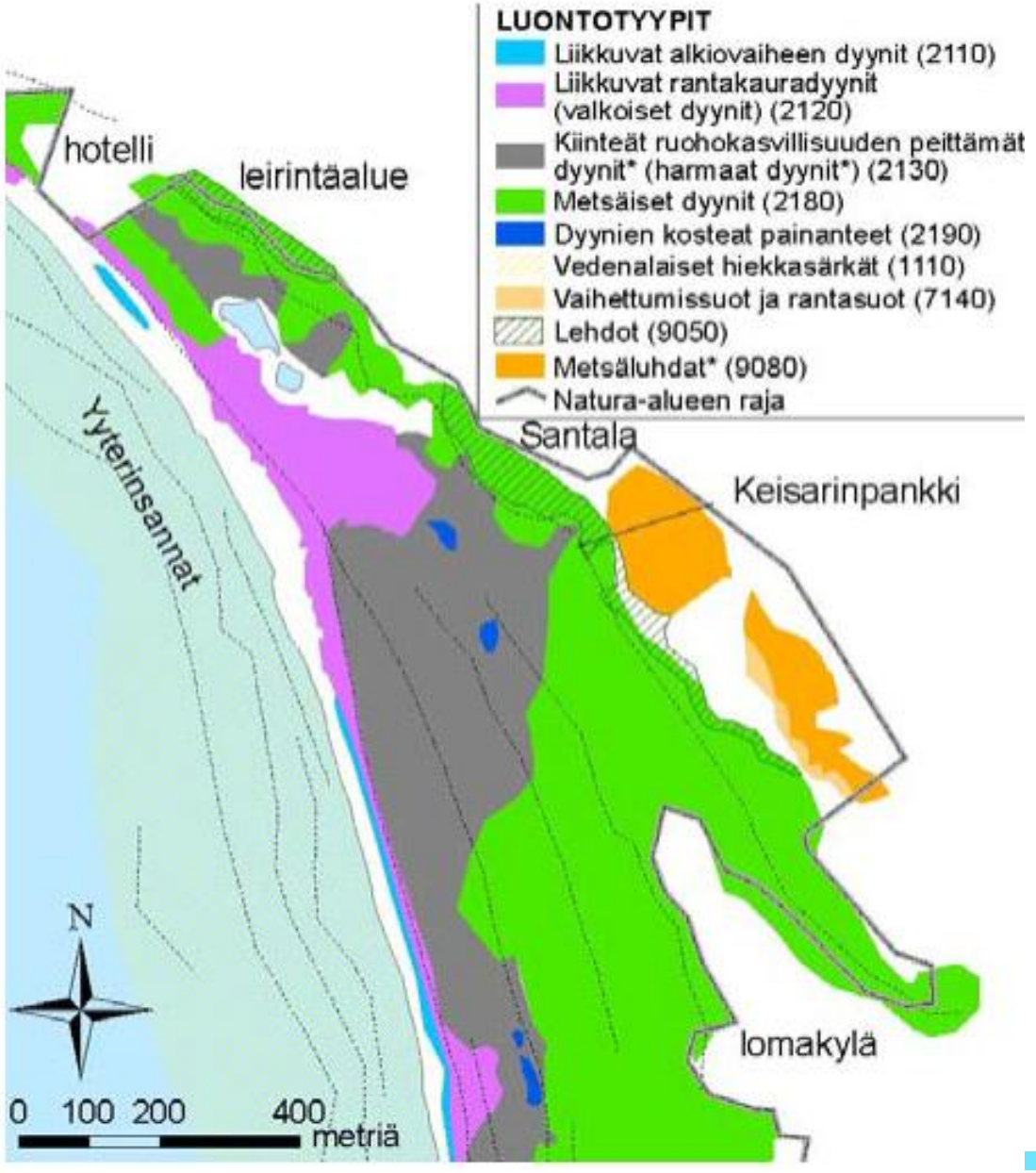
- Total area of the five different dune types: 93 ha, or ca. 1 km^2



Natural habitat types of Yyterinsannat

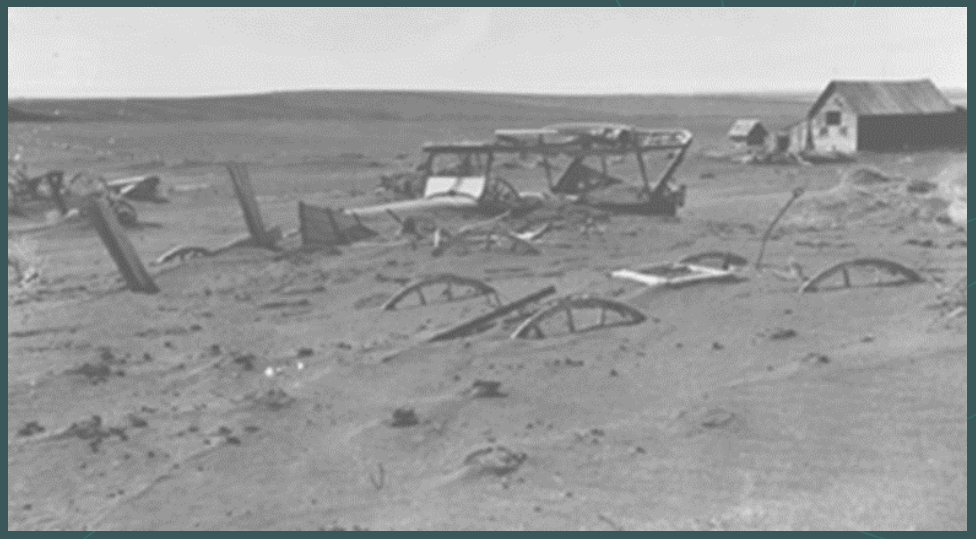
(for codes in English, see slide 34)

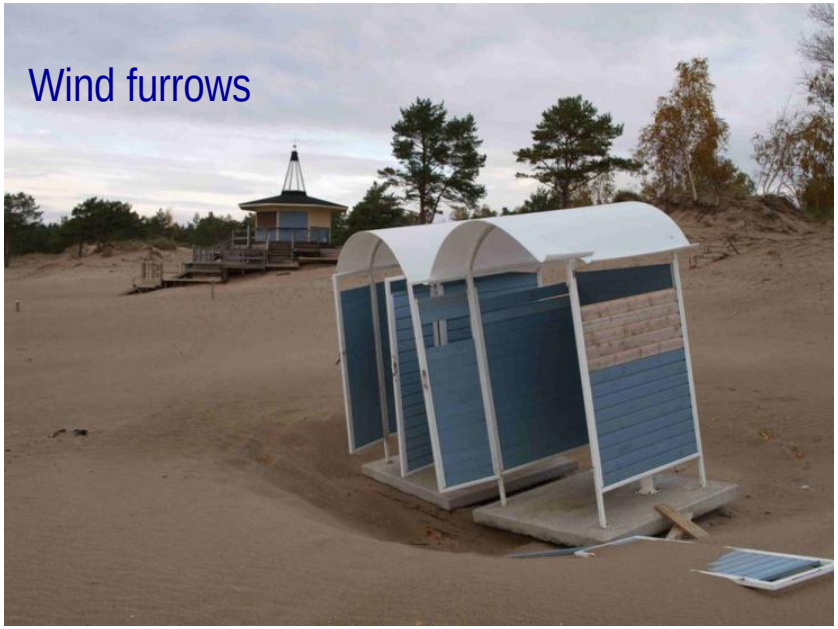


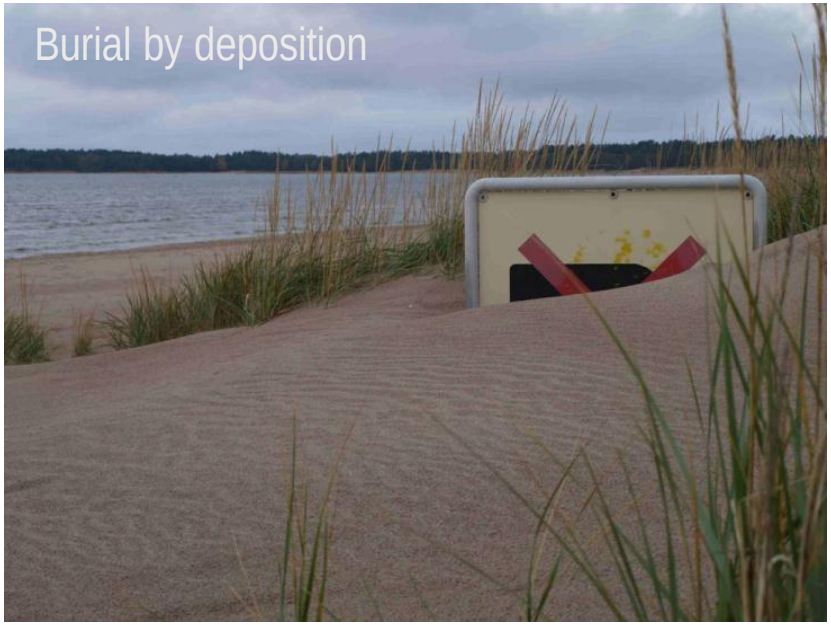


Wind erosion: deflation

- Occurs naturally on many dune types (e.g. parabel) and regions (e.g. surrounding glaciated terrains)
- Often accelerated by human activity (agriculture, grazing) when vegetation cover is sparse and sediment is fine (silt, loess)
- Ultimate example: the Dust Bowl of the 1930's in the United States







Yyteri Sands; examples of practical challenges

Turun yliopisto
University of Turku

Summary:

- **Dunes along the coasts of Finland are governed by:**
  - sandy glaciofluvial deposits on the shore and the sea bottom
  - gentle coastal profile
  - isostatic land uplift

à when these circumstances are met à coastal dune formation

- **Concern about dune management specifically in two environments:**
  - ***Active coastal dunes*** with high anthropogenic pressure
  - ***Partially active dunes of Lapland***, related to e.g. grazing pressure by reindeer (although much of the activity seems to be natural)